1-D Shock Tube Modeling Methodology for EAST

Maitreyee Sharma

University of Illinois at Urbana-Champaign

Aaron Brandis, Brett Cruden
NASA Ames Research Center

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Motivation

- Shock deceleration observed
- **Importance**: Deceleration affects the kinetics and hence the radiance of the system
- **Reason**: Interaction of the shock with the boundary layer
- **Objective**: Study the effect of the boundary layer growth on shock deceleration and kinetics of the system

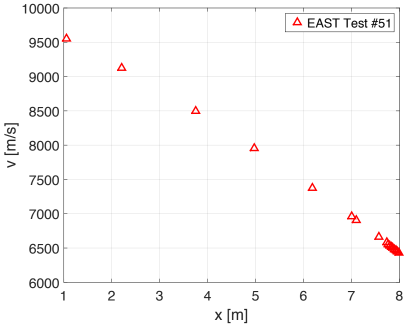

Figure: Velocity Profile from EAST

Develop a computationally efficient and fast tool to simulate every EAST shot

CFD Solver

- HEGEL - 1-D Flow solver with chemical non-equilibrium
- Thermodynamic and kinetics library: Plato

Euler equations for chemical non-equilibrium flow

$$\frac{\partial}{\partial t}\begin{pmatrix}\rho_i \\ \rho u \\ \rho E\end{pmatrix} + \frac{\partial}{\partial x}\begin{pmatrix}\rho_i u \\ (\rho u^2 + p) \\ u(\rho E + p)\end{pmatrix} = \begin{pmatrix}\omega_i - \epsilon \rho_i u \\ -\epsilon \rho u^2 \\ -\epsilon u(\rho E + p)\end{pmatrix}$$

ϵ is the area change coefficient.

> The source terms added to the equation represent the mass, momentum and energy lost into the boundary layer which in turn lead to deceleration of the shock

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Derivation done by Dr. Brett Cruden

Boundary Layer Modeling - Improvement from Previous Work

- To compute the shock arrival time accurately a Lagrangian approach is adopted
- Parallelization of the EAST simulation code. Serial code takes around 12 days to run full 8 m while the parallel code takes about 3.5 days. The current parallel simulation is run using 16 processors

EAST Simulations

EAST Simulation - Numerics

Time Integration Scheme : Forward Euler
Thermochemistry Model : 1 Temperature Model
Flux Scheme : Van Leer
Time Step : 0.3 ns
Cell Size : 1 mm

EAST Simulation - 1T, Quasi 1-D flow simulation

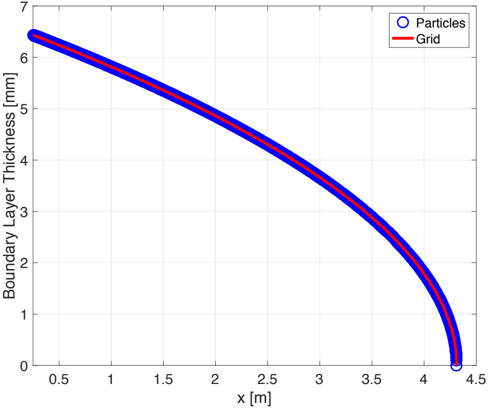
Driver Gas : Helium
Driver Gas Density : 1.10546 kg/m^3
Driven Gas : 79% N_2 & 21% O_2
Driven Gas Density : 3.096E-04 kg/m^3
Driven Gas Temperature : 300 K

Boundary Layer Growth

$$\delta = k\,\beta\sqrt{t - t_{arr}\left(x\right)}$$

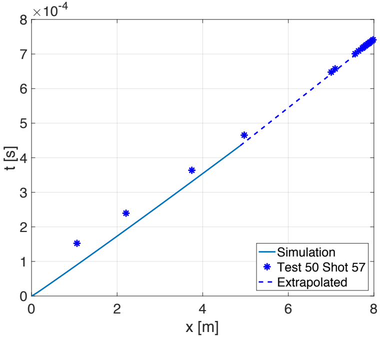
$$\beta = 4\sqrt{\frac{\mu}{\rho}}$$

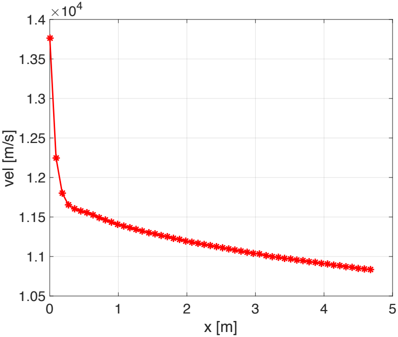
$$\epsilon = \frac{1}{A}\frac{\partial A}{\partial x} = \frac{-2}{R-\delta}\frac{\partial \delta}{\partial x}$$



The interpolation from a Lagrangian solution to the Grid (Euler Approach) is accurate

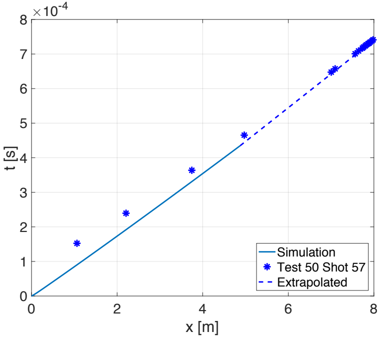
Comparison with EAST Data

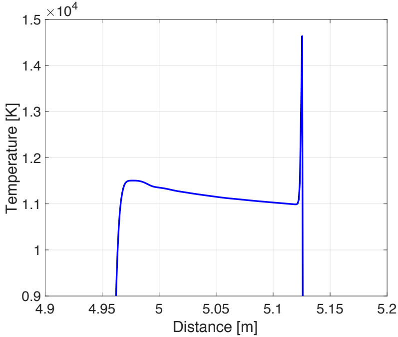




The shock deceleration is demonstrated using the quasi-1D approach

Comparison with EAST Data





The shock deceleration is demonstrated using the quasi-1D approach

Conclusions and Future Work

Conclusion

- Successfully demonstrated shock deceleration due to boundary layer growth in a quasi 1-D flow.
- Temperature profiles obtained from the simulations show a trend similar to that observed in EAST.
- Improvement and correction in the boundary layer growth achieved

Future Work

- Optimize the value of the scaling factor to match the results from experiments
- Run the two-temperature model to compare the radiation obtained from NEQAIR simulations to that of EAST
- Run the shock tube simulation for mars chemistry